XVII. Lunar and Planetary Sciences

SPACE SCIENCES DIVISION

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A. An Experiment for the Determination of Martian Surface and Cloud-Top Elevations,

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This experiment depends on the absorption of solar radiation in the Martian atmosphere by CO_2 molecules in both the 2- and 2.7-μ bands. In this spectral region thermal emission is negligible compared with reflected solar radiation; therefore, by pointing a spectrometer toward the Martian surface, the atmospheric absorption spectrum can be measured. The measured absorption will depend on the total amount of CO_2 in the radiation path as well as on the atmospheric pressure. If the mean atmospheric surface pressure is known and it is assumed that CO_2 is uniformly mixed, the anticipated absorption for a given surface elevation can be computed. Such calculations can then be compared with the measured absorption spectrum. As this experiment requires a measurement of absorption *relative* to the continuum, changes in surface reflectance with different kinds of underlying surface material do not affect the results.

Uncertainty in the value of the mean surface pressure does *not* render the experiment meaningless. It places uncertainty on the absolute elevation determinations, but relative elevation determinations are unaffected. Accurate measurements of absorption at these wavelengths would, as a by-product, lead to a better estimate of the mean surface pressure.

Although this experiment could be performed from either a flyby spacecraft or an orbiter, the latter would be preferable from the standpoint that detailed area coverage would be obtained and temporal variations could be measured.

In addition to elevation differences, several other factors will affect the atmospheric absorption. The most important are:

(1) Temporal changes—e.g., tidal effects and pressure fluctuations resulting from moving pressure systems; also, possible seasonal changes resulting from the changing size of the polar caps (if they are composed of CO_2).

(2) Spatial changes—e.g., a correlation between absorption and latitude could measure the planetary oblateness; mean atmospheric temperature changes will affect the absorption, but the atmospheric emission in the 4.3-μ CO_2 band should yield the mean temperature. Other spatial variations would be due to surface elevation differences.

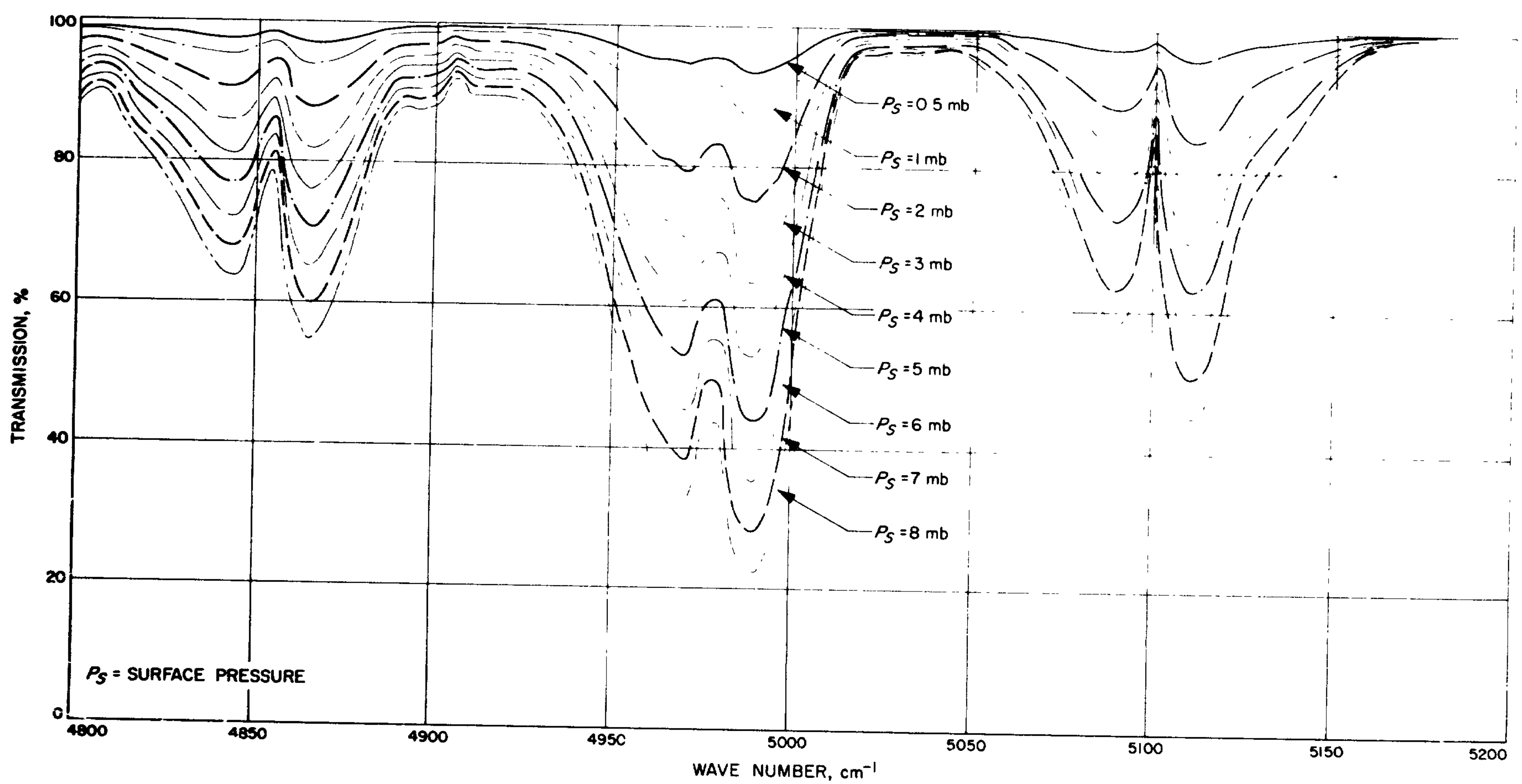

Fig. 1. Transmission of an assumed Mars atmosphere near 2 μ

Most of the above-mentioned effects are expected to be much smaller and of different spatial and temporal extent than elevation differences of the order of 1 km or more. Tidal effects may be of the order of 10%. The Mars circulation results generated by Mintz's program (Ref. 1) indicate that moving weather systems may cause pressure variations as great as 20%. The work of Leighton and Murray (Ref. 2) shows that polar caps could contain as much as one-third of the total atmosphere. The planetary oblateness is not well known, but de Vaucouleurs (Ref. 3) indicates that a flattening in excess of that associated with a geopotential surface seems to exist. The anomalous flattening suggests an increase in atmospheric mass in the polar region of the order of a scale height. The uncertainty in this result can be resolved as part of this experiment. If such an anomaly is not detected, this controversy may be dismissed.

Temporal and spatial correlations of the absorption measurements should yield information on some or all of the above effects. In this way, this experiment provides much more than a simple elevation determination. After the removal of temporal and low-amplitude spatial variations, elevation differences should be determinable to about 1 km. The following discussion supports this assertion.

Figs. 1 and 2 express the absorption by CO_2 of solar radiation that has twice traversed a hypothetical Martian atmosphere normal to the surface. The computer program and molecular spectroscopy used in deriving these curves were done by L. Gray.[1] The accuracy of the calculation has been verified by comparing calculated spectra with laboratory measurements (Ref. 4). The calculated absorption near 2 μ results from 45 different vibrational transitions; absorption near 2.7 μ is based on 67 different vibrational transitions. Figs. 1 and 2 have been drawn for 100% CO_2 atmospheres having surface pressures up to 8 mb. The successive curves correspond to reflection levels existing at lower pressures in 1-mb intervals; the top curve corresponds to reflection of solar radiation at

[1]On leave of absence from JPL Section 325.

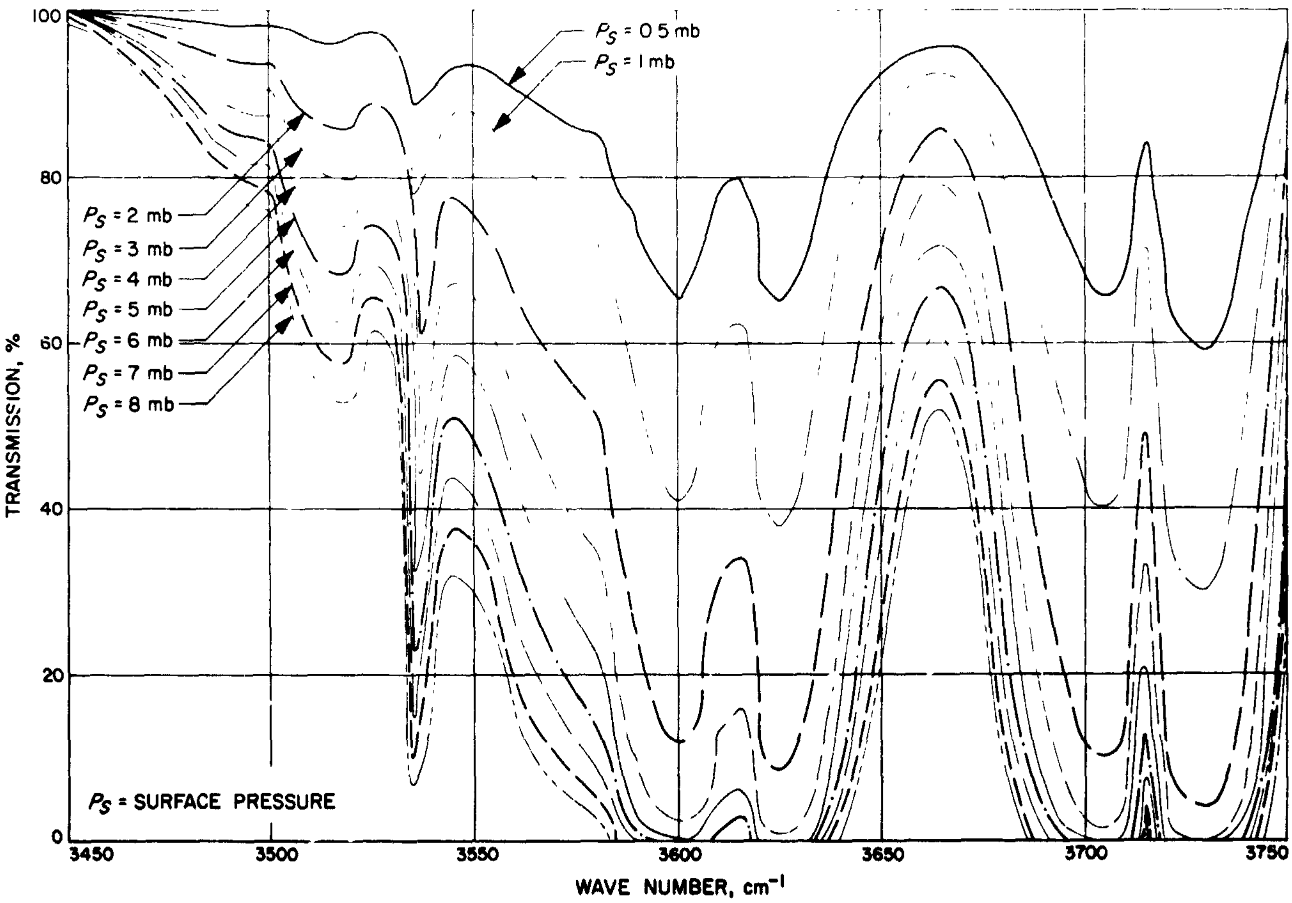

Fig. 2. Transmission of an assumed Mars atmosphere near 2.7 μ

the 0.5-mb level. The mean transmittance over a 10-cm^{-1} interval located near the peak of the P branch centered at 4980 cm^{-1} would be increased from 38 to 44% if an elevation difference of 1 out of 8 mb was encountered (under the assumptions of this atmospheric model). A change in surface pressure from 8 to 7 mb corresponds to a rise in elevation of about 1.5 km. An instrument having the capability of making a 1%-of-full-scale measurement could do better than this. It would be able to distinguish elevation differences somewhat less than 1 km.

Detectors placed in both the 2.7- and 2-μ spectral regions would be capable of measuring a wide range of absorption, corresponding to almost any conceivable model of the Martian atmosphere and to any conceivable elevation differences. The 2.7-μ band is considerably stronger than the 2-μ band and thus would offer a more detailed elevation determination should the mean surface pressure be considerably lower than anticipated. An examination of Figs. 1 and 2 dictates the detector wavelength settings required to carry out this experiment. There is much flexibility in the number and location of detectors, but detectors centered at 4970, 4980, 4990, 5040, 5090, 5180, 3450, 3515, 3600 wave numbers should yield useful results.

Detectors centered at 5040, 5180, and 3450 are used for background measurements to establish the continuum. It would be ideal to have at least these nine detectors; however, some useful information could be obtained with a lesser number.

It should be stressed that these calculations represent normal incidence and emergence of radiation. Although there is no such constraint, it is anticipated that measurements would be made looking straight down, normal to the planetary surface. However, it is necessary to know the direction in which the instrument is pointing as well as the angle the Sun makes with the local vertical. Calculations could easily be made for slant paths without seriously affecting the elevation determination, as discussed above. It would also be preferable to look down the local vertical in order to optimize the spatial resolution.

The above discussion applies with slight modification to the determination of the heights of the cloud tops. Although it is assumed that TV coverage of the areas being observed with the spectrometer will be available, it is suggested that an independent detection of visible radiation be made to establish the existence or absence of clouds in the field of view. The cloud top will act almost as a reflecting surface, but, in general, some correction for scattering within the cloud should be made. Saiedy, et al.,[2] find corrections ranging up to 38% when using the oxygen band near 7600 Å for similar measurements in the terrestrial atmosphere. It is anticipated that smaller corrections would be required at the longer wavelengths considered here, but there is strong dependence on particle size and optical thickness of the cloud. Detailed photographic coverage of the planet from the same spacecraft might yield valuable information concerning the nature of the clouds; this would aid in making corrections to the first-order estimate of cloud height (assuming that the clouds act as simple diffuse reflectors). It should be kept in mind, however, that the first-order estimate will be systematically an underestimate of the elevation of the cloud top. Multiple scattering in the clouds causes a greater increase in the radiation path length for absorption than would be observed under no-scattering conditions. This would be interpreted as a lower reflecting layer (i.e., at higher pressure) than actually exists.

Possible absorption due to any other molecules having absorption bands in the same spectral region should be considered. One such molecule that should be investigated is H_2O. Absorption due to 10 to 20 μ of precipitable water in the 2-μ region should be negligible (see Table 3-2 of Burch, et al., Ref. 5), but in the 2.7-μ region it may not be quite so small. Fig. 3 is a plot (taken from Ref. 4) of the transmission of radiation through 16.9 μ of H_2O vapor at a pressure of 200 mb. The conditions of the experiment are *not* the same as those in the Martian atmosphere. They should yield an overestimate of the absorption due to the high pressure in the absorption cell. The overestimate in absorption should be by about a factor of 5. This effect can be removed by measuring the absorption in an independent H_2O band, thus establishing the amount of water vapor in the radiation path. Absorption due to other more exotic molecules is expected to be small, and could be removed when positive identification of such molecules has been made and their abundances established by measuring absorption in other parts of the spectrum. In any event, as long as other molecules absorbing in the same spectral region as the CO_2 absorption are uniformly distributed in the atmosphere, relative elevation differences and cloud heights will be accurately determined.

This technique offers a straightforward method for establishing differences in elevation. Simplicity is its

[2] Saiedy, F., Jacobowitz, H., and Wark, D. Q., *On Cloud-Top Determination From Gemini-5*, personal communication.

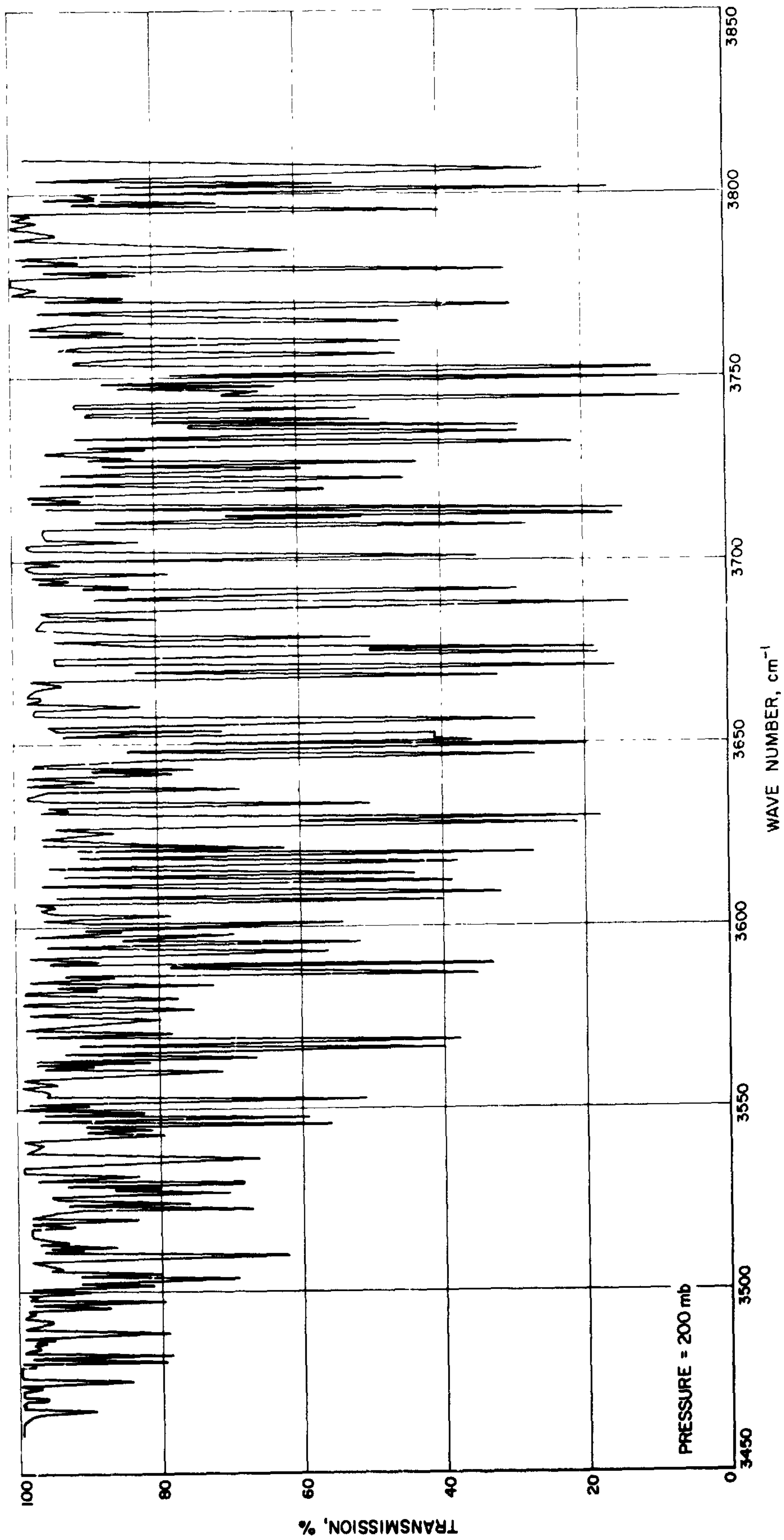

Fig. 3. Transmission of radiation through 16.9 μ of H_2O vapor

greatest asset. A glance at the results will yield valuable information, more detailed interpretation would serve to refine the initial estimate and yield additional important results. Although the cloud-height problem is not quite so straightforward, even there a glance will yield significant information that is not obtainable by any other means.

B. Balloon Observations of the Radiance of the Earth Between 2100 and 2700 cm⁻¹, *J. H. Shaw,[1] R. A. McClatchey, and P. W. Schaper[2]*

The retrieval of atmospheric temperature information from observations of the outgoing thermal radiation from a planet in a spectral region occupied by a strong band of an atmospheric gas whose distribution with height is known has been described by Kaplan (Ref. 6). Hilleary, et al., (Ref. 7) have successfully used this method to determine an atmospheric temperature profile to 30 km by measuring the upward radiance from the ground and the CO_2 in the atmosphere in narrow spectral intervals near 15 μ with a balloon-borne grating spectrometer.

Carbon dioxide is the only strongly IR-absorbing atmospheric constituent whose distribution with height is known with some certainty. This molecule has strong bands at 4.3 and 15 μ. The 15-μ band is the weaker of the two, but it occurs at a wavelength near which the outgoing radiance from the Earth is at a maximum. The 4.3-μ band lies in a region where the outgoing thermal radiation flux is small, but strongly temperature dependent. This band can also be used to determine atmospheric temperatures. McClatchey (Ref. 8) has shown that suitable experimental data for such an analysis can be obtained with a spectrometer that has a spectral resolution of 100 and can determine the flux in this region from a 200°K blackbody with a signal-to-noise ratio greater than 10.

A grating spectrometer capable of measuring small radiation fluxes with a spectral resolution of 95 at 4.3 μ has been constructed and flown on a balloon from Sioux Falls, South Dakota. Bands of CO_2, N_2O, and O_3 are identified in spectra of the Earth and lower atmosphere between 2100 and 2700 cm^{-1}. Measurements were made at an altitude of 30 km. Scattering of solar radiation by clouds was observed between 2400 and 2700 cm^{-1}. A temperature profile of the atmosphere to 30 km determined from an analysis of the measurements in the region of the 4.3-μ CO_2 band was compared with radiosonde observations made during the flight.

A more complete account of the instrumentation and the data is given in *Applied Optics*, Vol. 6, No. 2, p. 227, February 1967.

[1]Ohio State University, Department of Physics, Columbus, Ohio.
[2]JPL Section 323.

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